SYSTEM AND METHOD TO QUANTIFY APPEARANCE DEFECTS IN MOLDED PLASTIC PARTS

BACKGROUND OF THE INVENTION

This invention relates generally to measuring appearance variations in molded plastic parts, and specifically to tools for duplicating the streaking seen in real parts and measurement and analysis of the streaking.

Consumers of durable plastic products including, for example, toys, computer and printer housings, and vehicles expect a uniform surface finish with no visible flaws, streaks, or defects. Common defects include streaks where various plastic flows meet in a part. These streaks may arise as different flow fronts from different gates meet or downstream of flow disruptions such as grills, bosses, ribs, or holes.

Currently, few, if any, numerical specifications related to uniformity of appearance are given to a supplier of raw plastic products outside of average color and possibly gloss or haze. Nevertheless, the molder creating the part and the consumer each expect a product with no visible flaws. The consumer, in particular, may view appearance defects as both unsightly and as indicative of poor quality material.

Currently, the quality, uniformity, and lack of defects in a part is typically judged using visual inspection on production parts. This leads to an absence of numerical specifications, lack of consistency due to operator variation, and an inability to consistently and rapidly process a large number of samples. Further, a large amount of waste may be generated since a large number of defective parts must be molded to attempt to quantify the problem. Often, the molder or customer is unable to transmit a complaint to the plastic supplier that is more specific than "a streaking problem exists," and many pounds of rejected production parts are shipped back to the plastic supplier for subsequent visual evaluation. Yet, it is difficult for the supplier to address the problem and provide solutions in the absence of effective measurement tools.

Several prior commonly-assigned and invented patents and patent applications, namely, U.S. Patent 5,859,708, issued 1/12/99; and

application serial numbers 09/075,913; 09/188,094; and 09/188,095; address vagaries of visual inspection via a spatially resolved spectrometer which can resolve small defects that are not apparent to a standard spectrometer with the typical ½ inch diameter or larger aperture. Further, unlike the few spectrometers capable of smaller apertures that are not automated, the spectrometer described earlier may be interfaced with a computer for motorized sample movement and automatic data collection.

However, several problems remain. First, complex, curved, or textured parts are not amenable to automated inspection. Second, this spatially resolved spectrometer generates massive amount of data and automated data reduction is necessary to screen parts.

Accordingly, there is a need in the art for and improved system and method to quantify appearance defects in molded plastic parts.

SUMMARY OF THE INVENTION

A molding tool that duplicates streaking seen in real parts is used to produce molded plastic part samples that include selected topological surface features (e.g., ribs, holes, grills, bosses) of production molded parts to be subsequently produced. A spatially-resolved spectrometer is used to measure color characteristics spatially along the sample part. Finally, a computerized device is used to appropriately filter the data and quantify the streaking in terms of overall data shape, average peak and valley shift, and a quality number indicative of data slopes. Based on this process, which process may be iteratively applied to one or more series of samples, an optimal prescription of ingredients (e.g. plastic pellet characteristic, color dye mixes) and production conditions (e.g., temperature, extrusion rate) is identified for producing the production molded parts.

Once these optimal ingredients and conditions are specified, the production molded parts can then be produced properly the first time, in a way that minimizes streaking given the particular surface topology of those parts. This saves the time and expense of unsuccessful, defective production runs.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic illustration of a spatially-resolved spectrometer according to one embodiment of the invention, for obtaining color readings from a plastic part being examined and analyzed;

FIG. 2 is a plan view of the molding tool in accordance with one embodiment of the invention;

FIG. 3 is a plan view illustrating various mold configurations for use in connection with the molding tool of FIG. 2;

FIGS. 4 and 5 are flowcharts illustrating methods of post-processing color readings according to embodiments of the invention;

FIGS. 6 through 9 illustrate sample data representative of color signal shape including peaks and valleys, as that data undergoes several iterations of post processing filtering according to the invention;

FIG. 10 illustrates a method used to calculate a quality measure of the sample under consideration according to one embodiment of the invention, from the sample data of FIGS. 6 - 9;

FIG. 11 illustrates the method used to describe the shape of the sample data of FIGS. 6 - 9.

FIGS. 12 and 13 illustrate the method used to average the degree of variation from peak to valley over the entire sample, using the sample raw data of FIG. 6.

DETAILED DESCRIPTION OF THE INVENTION

The several commonly-invented and commonly-assigned issued and pending U.S. Patents noted earlier disclose a spatially-resolved spectroscopic tool for measuring visual characteristics of plastics, such as color, color blending, coining (e.g. scratching), etc.

The system and method, according to one embodiment of the invention, generally comprises three parts: A molding tool that duplicates the streaking seen in real parts, the a spatially resolved spectrometer to measure color along the surface of the part, and post processing software to quantify the streaking. Various parts of the system may also be used alone, as appropriate.

As used herein, the term "samples" will be used to refer to molded plastic parts produced by a molding tool according to the invention, while "production" will be used to refer to a molded plastic part (such as a computer monitor housing, a printer housing, a television housing) that is the ultimate object to be produced using the analysis tools provided according to the invention. In this context, the invention involves creating and using "sample" plastic parts to determine the optimum prescription for producing "production" plastic parts, so that defective production of production parts, and the cost and time for producing such production parts, is minimized.

As illustrated in FIG. 1, spatially-resolved spectrometer **1** is used in a manner similar to the disclosure of the above-referenced pending and issued U.S. Patents. Color measured by spectrometer **1** is output in any conventional color format **10**, such as but not limited to, CIELab units L, a, b. A molded plastic part **11** (which plastic part **11** may be a sample or a production part, but in this illustration is a sample) is evaluated by directing incident light **12** from a light source **13** onto plastic part **11** at a sample point **17**, and reflected light **14** from sample point **17** is measured using spectrometer **1**. Incident light **12** and reflected light **14** are carried to and from plastic part **11**, for example, via light carriers **15** such as optical fibers, and are focused at sample point **17** as needed using focusing elements **16** such as one or more optical lenses. Incident light **12** may or may not be "focused" at sample point **17** in the scientific sense; so sample point **17** is simply to be understood as a point upon which light impinges **12** and is reflected **14**. In order to evaluate streaking **18**, plastic part **11** and sample point **17** are movable relative to one another in any direction along any combination of the x-y-z axes illustrated. A plurality of readings may thus be taken from different locations upon plastic part **11** at a plurality of locations spatially separated from one another by predetermined distances and directions. In this illustration, the samples are taken linearly **19** along the x axis. These readings are then input to the post-processing software for quantification and analysis. Molded plastic part **11**, when it is a sample

plastic part produced according to the invention, will also sometimes be referred to as a "mold" or "plaque." The color format measurements **10** are then forwarded to a computerized device **101** for post processing as described in FIGS. 4 through 13.

In one embodiment, spectrometer **1** and light carrier (e.g. fiber) couplings **15** are used in a 0-45 configuration, wherein incident light **12** impinges plastic part **11** at an angle of substantially zero degrees from perpendicular (i.e., normal to the plastic part **11** surface) and reflected light **14** is captured at an angle of substantially forty-five degrees from perpendicular. In other embodiments, incident light **12** angle is between zero and thirty, zero and forty five, and zero and eight-nine degrees from perpendicular. In other embodiments, reflected light **14** angle is between thirty and sixty, and between zero and eighty-nine degrees from perpendicular.

When a sample plastic part **11** is used, plastic part **11** may be mounted on a sample holder that is optionally mounted on motorized translation stages, so as to scan across the feature of interest. A computerized device (not shown) comprising computer software or hardware automates the motion system and data collection, and transforms the raw data into color coordinates. The computerized device guides the user through necessary calibration activities and allows the user to optimize the signal to noise by allowing adjustment of key parameters. Manual adjustment of the sample to selected locations is also possible, if desired.

The molding tool, illustrated in FIGS. 2 and 3, comprises a system that allows the user to duplicate streaking from real parts on a laboratory scale. Samples produced in the molding tool are typically flat with a smooth, uniform surface finish, making them the ideal samples to be evaluated using the spatially resolved spectrometer.

A sample mold, such as a two-cavity molding tool **2** illustrated in the preferred embodiment of FIG. 2, comprises a single gate cavity **21** to produce single-gate plaques, and a double-gate cavity **22** used to produce double-gate plaques with knit lines. Extrusion of molten plastic from sprue **23** into one or both cavities **21** and **22** is controlled by valves at appropriate locations

24 in runner **25**, and may be shut off or turned on as needed. A variety of inserts may then be placed into one or more insert receptacles to obstruct the flow (increase the chance to have streaking), for example, at any or all of the three different insert locations **26** in the single-gate cavity as shown. Molten plastic enters cavities **21** or **22** through gates **37**.

While the dimensions can obviously be varied widely within the scope of the invention, cavity **21** and **22** have a preferred length **27** of approximately four to six inches, and typically about five inches, a preferred width **28** of approximately two to four inches, and typically about three inches, and a preferred thickness (not shown) of approximately 1/32 to 1/8 inch, and typically about 1/16 inch. The goal is to have small-scale, easily molded and handled samples, which have a smooth, flat surface finish for best evaluation using the spectrometer. Thus, any particular size and thickness may be chosen within the scope of the invention which best duplicates the results seen in production samples on a smaller scale, even outside the ranges enumerated above. Thickness, in particular, may depend on plastic formulation, properties such as melt temperature and viscosity, and final production part thickness. Insofar as weight in concerned, a Cycoloy C6200 part and runner, for example, weighs approximately 1.2 oz (33 g). While the Cycoloy C6200 is used for a specific plastic formulation, any formulation of interest could be used for producing sample plastic parts according to the invention. The weights would generally be similar for different plastic formulations.

FIG. 3 illustrates various sample plastic part (plaque) **11** configurations that can be produced utilizing various mold inserts in connection with the molding tool of FIG. 2. In particular, a plurality of molding tool inserts are inserted into one or more of the insert location **26** of molding tool **2**. Each such insert is designed to produce, for example, molds (plaques) **11** with a "hole" **31**, "boss" **32**, "rib" parallel to the plastic flow **33**, "rib" across the plastic flow **34**, "grill" parallel to the plastic flow **35**, and "grill" across the plastic flow **36**. The configurations illustrated in FIG. 3 are produced by placing a single "topological" insert into the insert location **26** closest to gate **37** of single gate

cavity **21**, and a pair of "blank" inserts into the remaining two insert location **26** of single gate cavity **21**. Thus, the molding tool inserts are illustrated in terms of the "negative" of the surface features **31**, **32**, **33**, **34**, **35**, **36** illustrated in FIG. 3. It is understood therefor, that reference to, for example, a "boss" insert **32** refers to an insert that when inserted into single gate cavity **21**, and after molten plastic is extruded into single gate cavity **21**, will produce the topological surface feature illustrated by **32**. Similarly, general references to molding tool inserts **3**, will be understood to refer to molding tool inserts that embody the negatives of, and produce surface features such as, those illustrated in connection with the six plaques **11** of FIG. 3.

The six particular configurations illustrated in FIG. 3 are typical of the "topological" surface features commonly encountered in "production" plastic moldings, and so enable "sample" moldings to be produced that have surface features that will be produced in the production moldings for the planned production runs. Of course, these are just examples of the types of configurations that can be produced by the inserts, and it is understood that molding tool inserts **3** that are designed to produce additional surface features not expressly illustrated in FIG. 3 may also be developed and used according to the invention. Also, the ribs and grills (and any other surface features produced by other insert types that are not radially symmetric) can be oriented at any angle relative to the main flow through gate **37**. Similarly, while double gate cavity **22** utilizes two gates **37** with substantially parallel input, it is understood that any number of gates can be used, with varying relative orientations to one another, in accordance with the invention.

Thus, in use, if it is known that a "production" plastic part to be manufactured is to have certain topological features, either separately or in combination, "topological" molding tool inserts **3** are placed into one or more of the insert locations **26**, and "blank" inserts are placed into any remaining insert locations **26**. Then, molten plastic is extruded into single gate cavity **21** or double-gate cavity **22** via gates **37**. (Double-gate cavity **22** may be used where it is known that the production plastic part will be produced by double gate injection.) The plastic is allowed to harden, and the resulting plaque(s),

with surface features such as **31-36**, and with double-gate injection features if pertinent, are removed and placed under spatially-resolved spectrometer **1** as earlier described in connection with FIG. 1 The streaking **18** resulting from the topological feature or features of interest (or from double gate if double-gate cavity **22** is used) is then analyzed by spectrometer **1** as discussed below. It is to be noted that the plaque **11** used as an example in the illustration of FIG. 1 is one with a "grill" parallel to the plastic flow **35**.

As detailed below in the discussion of FIGS. 4 through 13, post processing using a computerized device comprising hardware or software in appropriate combination, reduces noise by smoothing the raw color scans and calculates the difference in L values (using CIELab color space) between the lightest and darkest points across a streaked region. That is, if a dark line is observed down the part, it is desirable to look at the "normal" color on either side of the line as well as the variation from one "normal" region to the other across the discoloration. Various embodiments are possible. For single-streak parts, Delta L or area under the curve may be calculated. For parts with multiple streaks, the values for each streak may be averaged or the values for each streak may be reported individually. The user may also choose to view either the raw data or the smoothed data with no further post processing. While this invention is described with reference to CIELab color space, it is understood that any other means of characterizing and analyzing color can also be used in accordance with the invention.

Once a number of molded plastic part samples have been produced and each has been scanned by spatially-resolved spectrometer **1** according to the invention as described in reference to FIGS. 1 through 3, it is desirable to compare the various samples and determine which sample has the optimum appearance. This in turn makes it possible to determine which mix of ingredients and which set of processing conditions should be used in production.

There are three primary types of data that are made available for this purpose according to the invention. First, since the slopes of the peak and valley curves represent how rapidly color variations take place from one space to the next in any given sample, and since smoother (lower slope)

variations are preferred to sharper (higher slope) variations, it is desirable to obtain a "quality" measurement based on these slopes. Second, it is desirable to obtain a detailed description of the overall shape characteristics of the appearance of the sample. Finally, one measure of the desirability of any given sample is based on height variation from each peak to the adjacent valley, as well as on an overall average of these. In all cases, since there will be statistically insignificant color variations measured from one linear position to the next for any given sample, it is desirable prior to performing any of these calculations to filter out these insignificant variations to obtain a plotting of true peaks and valleys, over the space being considered, for each sample.

FIGS. 4 and 5 are flowcharts illustrating this overall calculation process. At **402**, computerized device **101** first determines the overall number of plastic part samples **11** that have been scanned for analysis. In the discussion to follow, the term "sample" or "sample data" will generally be used to refer to the overall set of CIELab (or similar measure) color data points obtained by the process outlined in FIGS. 1 through 3, for each plastic part sample. For example, if a dozen plastic part samples were produced and scanned, there would be twelve sets of sample data associated with these twelve part samples, and each data sample would contain a number of data points. At **404**, names or similar identifiers associated with each sample are established, along with the number of data points for each sample. The first data point for each sample is similarly identified. At **406**, each data point is stored in the computerized device with several associated pieces of information, including the sample name or identifier, the number of that particular point in the overall sample, the spatial position of that point relative to the origin (i.e., the first data point for that sample), and the L, a and b values. At **408**, the data is examined for completeness. It is determined if all required data fields are present (sample name or identifier, point number in sample, spatial location on sample, L, a, b) and if the numerical fields (all but the name) are numerical. From **408**, incomplete raw data is eliminated at **410**, **412** and **414**, while complete raw data is then analyzed for one sample at a time at **5**, using the process summarized below in connection with FIG. 5, until the analysis is complete for all samples. The results are

then output at **416** to a suitable data output device such as a spreadsheet, computer display monitor, printer, etc. in a suitable data format such as numeric data, graphical representation, etc. The process concludes at **418**.

In FIG. 5, which comprises step **5** of FIG. 4 and illustrates the overall processing of data for a single sample, computerized device **101** first obtains the raw data for the given sample at **50**. Then the first of the three above-referenced calculations – the quality calculation **51** – begins.

At **511**, small fluctuations in L, a, b indiscernible to the human eye are filtered out, using a multilinear fit to a series of points using parameters to define the accuracy of the x and y coordinate fit. As illustrated in FIG. 6, local "noise" in the raw data is filtered out, and only variations above certain predefined threshold parameters are maintained. This results in the "compressed" data plot superimposed over the corresponding "raw" data plot in FIG. 6. At **512** and **513**, this compressed data is then further filtered through several iterations (in this example, three) illustrated in FIGS. 7, 8 and 9. The first iteration at **512** (FIG. 7) identifies all local extreme, i.e., maximum and minimum, points. Detecting local minimum and maximum values allows determination of defects or inconsistencies in the sample such as "streaking." The second iteration at **513** (FIG. 8) removes from the data set, all minima and maxima with a change in L (or a and b for those calculations) from the adjacent minima and maxima below a predetermined limiting value, so that only significant variations are maintained. The third and final iteration, also at **513** (FIG. 9) then returns to the data set any minimum point that has a high maximum point on one side and a low maximum point on the other side. The data output from **513**, illustrated by the example in FIG. 9, will be henceforth referred to as (final iteration) "filtered" data. Fluctuations in L, a, and b values following this filtering indicate changes in the appearance of the sample.

Next, a quality number is calculated at **514**. The Quality number is a way of ranking the samples according to the number of streaks apparent and the signal intensity shift. It is linearized **515** so that ranking of several test samples is scaled correctly. FIG. 10 illustrates a sample calculation of

this quality number. If Q = quality number, Σ dL/dx = the sum of the slopes of the filtered data from **513**, and M = a suitable multiplier such as 1000, then:

$$Q = \ln (M * \Sigma DL/dx) \qquad (1)$$

Similarly, for a and b data, once simply substitutes a and b for L in the above. By its relation to the first derivative (slope) of the L, a and b curves, Q essentially measures the smoothness or sharpness of any measured streaking. As noted above, this is the first of the three primary measures used to determine which among all samples is to be used as the basis for a full-scale production recipe.

Next, at **52**, the overall shape characteristics of the data are described, using the same filtered data from **513** (illustrated in FIG. 9) that was used to calculate quality number Q. Using this filtered data at **521**, one arrives at a clear representation of signal peaks that can then be quantified in various ways as shown in FIG. 11. Data taken from various samples in fact shows that different types of defects give different looking peak shapes. At **522**, descriptive data such as height, slope, width, and curve shape allows the user to quantify and qualitatively describe the difference between samples. The number of defects in a sample as well as the signal intensity of each individual defect are important to the user. This is the second of the three primary measures used to determine which among all samples is to be used as the basis for a full-scale production recipe. Some example width, height and slope data resulting from shape analysis **52** are illustrated toward the upper right of FIG. 11.

Finally, L, a, and b shift calculations are performed at **53** to describe the signal intensity shift and color shift across the sample taken. Whereas quality calculation **51** and shape analysis **52** share the same compressed **511** and filtered **513**, **521** data, shift calculation **53** in the preferred embodiment does not. At **531**, local "noise" in the raw data is filtered out, and only variations above certain predefined threshold parameters are maintained, resulting in a second compressed data set similar to that obtained in **511**. However, it is generally preferred to use a different set of

threshold parameters for shift calculations 53 than for quality 51 and shape 52 calculations and analysis. Similarly to **512**, local maximum and minimum points are again obtained **532**, but again, these are based on the preferably different threshold parameters used at **531**. The three filtering iterations **513** are not performed. Then, at **533**, the shift is computed. FIG. 13 illustrates this for a sample L shift calculation. Peaks below a certain predetermined threshold height are then discarded, and the L shift, as well as a and b shifts, are calculated from peaks above that predetermined threshold **512**. If S = shift, T = total sum of peak heights above threshold, and N = number of peak heights above threshold, then

$$S = T / N. \qquad (2)$$

That is, the shift simply measures the average peak height of a given sample, which as noted earlier, is the third of the three primary measures used to determine which among all samples is to be used as the basis for a full-scale production recipe. If desired, the individual shifts may be reported rather than the average.

It is understood that FIGS. 6 through 13 illustrate graphical representations of numeric data stored in and operated upon by computerized device **101**, and of course, that FIGS. 6 thorough 13 are simply illustrative of the invention and not limiting. It is further understood that this numeric data, including numeric data indicative of such features as coordinates, slopes, shapes, etc., can be represented within computerized device **101** in a wide variety of ways that would be apparent to someone of ordinary skill. Finally, it is understood that specific manners of representing the numeric data underlying FIGS. 6 through 13 in computerized device **101** using practices common in the art is considered to be within the scope of the invention and the claims associated therewith.

This system may be used to quantify all manner of appearance defects, including light and dark streaks, splay, surface defects (gloss or roughness), and others.

While only certain preferred features of the invention have been illustrated and described, many modifications, changes and substitutions will

occur to those skilled in the art. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.